Experimental Setup for Human Aware Navigation

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***Abstract*— Validation of algorithms developed by assistance robotics research on real platforms is essential. Producing robotic architectures that promote scientific advances while regarding usability for the final user is a challenging issue where an appropriate trade-off between both requirements must be found. This paper proposes a new framework for the development of mobility assistance techniques to improve the quality of life of elder population using a robotic wheelchair. An example of improvement of the wheelchair navigation is presented. The control of the wheelchair is done using a Bayesian semi-autonomous approach that estimates the user intended destination from input commands given through a Kinect sensor. Safe and comfortable autonomous navigation is performed using a probabilistic navigation method that takes into account the dynamics of the environment and human social conventions.**

Keywords: robotic wheelchair, human centered robotics, human aware navigation, assistance robotics, shared control, Bayesian inference,

I. Introduction

The aging of world's population is bringing the need to provide robotic platforms capable to assist elder people to move. These robots can be vehicles or wheelchairs and is necessary that such transportation is reliable, safe (at least as much as a human) and comfortable.

Patients and medical staff have a strong desire for the services that a smart wheelchair can offer [1]. Some users cannot use a normal power wheelchair because they lack the required motor skills, strength, or visual acuteness.

When using a robotic wheelchair, the occupant must feel that this mode of travel is tailored to its needs. The vehicle or wheelchair must meet specific needs: those of people with disabilities or reduced mobility or just those of people without disabilities but who want a service of comfort .

No matter what the mobility assistance device is (car, wheelchair, walking aid...), navigation in human environments is a central problem. If one aims to develop a robotic device, it must combine many technologies proposed in the robotic domain: perception, prediction, fusion, navigation, control, but also must integrate social conventions knowledge and a way to share the control with the user in order to guarantee a safe navigation while avoiding frustration due to the disregarding of the user desires by the autonomous navigation system.

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In this article, an architecture combining all these technologies and some experiments on a robotic wheelchair are presented.

Section II presents related work on automated wheelchairs. Part III describes the system architecture with a focus on the human intention estimation process and human aware navigation method. Sections IV and V present the experimental platform and section VI details the results. Conclusions are discussed in section VII.

II. Related Work

The growing interest in producing an autonomous wheelchair to assist elder people mobility has led to the development of many different wheelchair platforms [2]. Most of the presented wheelchairs operate in a manner very similar to autonomous robots; the user gives the system a final destination and supervises as the smart wheelchair plans and executes a path to the target location (e.g.,NavChair [3], MIT Media Lab wheelchair [4]).

Other smart wheelchairs confine their assistance to collision avoidance and leave the majority of planning and navigation duties to the user. These systems do not normally require prior knowledge of an area or any specific alterations to the environment. They do, however, require more planning and continuous effort on the part of the user and are only appropriate for users who can effectively to plan and to execute a path to the destination. A final group of smart wheelchairs offers both autonomous and semi-autonomous navigation (e.g., VAHM [5], Sharioto [6], SmartChair [7]).

Whenever two or more entities aim to work together they must be able to communicate their intentions to each other. When a human is driving an automated wheelchair, the explicit communication of users plans is not always possible which leads to the development of techniques to estimate the user intention implicitly. The implicit estimation of the user intention provides an easier control of the robotic system (wheelchair) for user's who cannot give accurate or fast commands due to its handicap. Some methods are presented in [10], [11] [12].

Recent works have focused on the understanding of social interactions between humans to provide socially accepted movement to increase the comfort for the user [8], [9].

III. System Architecture

When performing robotics research, often the scope of the investigation is limited to a well-defined area of the system, such as a software module which performs some type of planning, reasoning, perception, or control. However, to get a robotic system up and running for experiments, a much larger software ecosystem must exist.

Fig. 1 presents an overview of our systems architecture. It is divided into several subsystems, some of them are being developed by our team while others were taken from external sources to perform necessary tasks that are not crucial for our research domain.

- *User Intentions Estimation*: The user intention subsystem estimates the desired goal within the map of the environment among a list of possible predefined goals. Those locations can be previously selected by an expert caregiver, the user, or learned by the system using machine learning techniques. The user intention estimation computes the probability for each typical goal given the current position of the wheelchair and the user command and then selects the goal with the highest probability. The computation of probabilities is done using a Bayesian network approach.
- *Tracking*: The off-board tracker provides global information about moving obstacles which is the learning input for our motion prediction module. It is built as a conventional detect-then-track system. The tracking subsystem is also necessary to identify the interactions between people (e.g. two persons involved in a conversation).
- *Prediction*: Processes data from the trackers and transforms it into probabilistic predictions about the configuration of the free space in the future environment. The motion prediction subsystem takes tracking data (i.e. position, orientation and velocity) and outputs grids, representing the posterior probability of the space being occupied at a given time step in the future. Prediction itself is accomplished with a Growing Hidden Markov Model (GHMM) [13] and an Extended Kalman Filter.
- *Social Filter* Detects social interactions and creates virtual obstacles corresponding to those interaction zones. In order to produce socially acceptable motion, it has been proposed the 'Social Filter', which integrates constraints inspired by social conventions in order to evaluate the risk of disturbance and take it into account when making the autonomous navigation planning. We focus on detecting and predicting conversations in the environment surrounding the wheelchair [9].
- *Motion Planning*: The navigation subsystem includes a laser-based localization module and a motion-planner which integrates predictions to compute safe trajectories that are fed to the execution module. The motion planner is based on Risk-RRT [14], a partial motion planner which integrates motion predictions to provide safe trajectories. This algorithm was thought to operate in dynamic, uncertain environments, it supposes that the moving pedestrians detected in the environment follow typical motion patterns that are represented by Growing Hidden Markov Model (GHMM). This motion planner generates human friendly paths respecting people's personal and interaction spaces, as provided by the social filter.

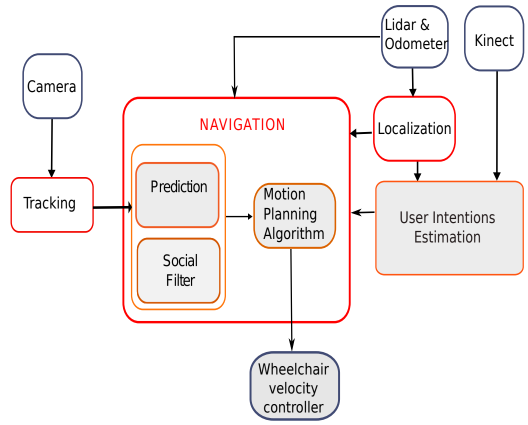

Fig. 1. System architecture overview.

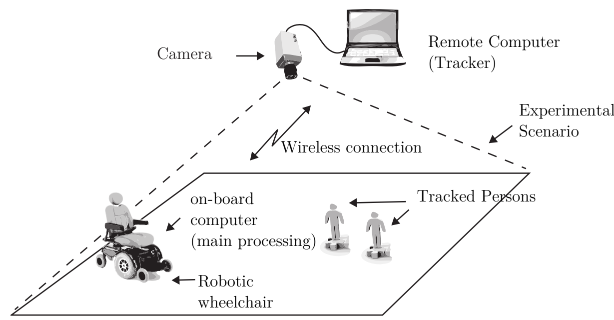

Fig. 2. Overview of the full experimental setting

IV. Experimental Platform

The proposed experimental setting is shown in figure 2. The main entity is the robotic wheelchair with all the on-board sensors and computer. The scenario proposed for the experiments is a human populated environment where people can be moving and interacting. Those persons can be tracked using the camera mounted on the top of the scenario. A remote computer is in charge to send the tracking information to the wheelchair.

A. Visual Tracking System

A camera mounted over the scenario is used to track the present people. A marker based visual tracking system [16] is used to accurately track the position and orientation of special marked cards. In order to track the people in the experimental scene they wear markers on their heads as seen in figure 3.

B. Wheelchair

The equipment used is the robotic wheelchair shown in figure 4 that consists of a mobile base equipped with the seat, all the on-board electronics and different attached devices. Sensors on-board the wheelchair consist of a LIDAR (Light Detection and Ranging) model SICK LMS-200, wheel based quadrature encoders for odometry measurements and

Fig. 3. Three tracked persons interacting at INRIA's hall

Fig. 4. Robotic wheelchair used for the described experiments.The mobile base includes all the electronic components and the computer in charge of the low level control of the wheelchair

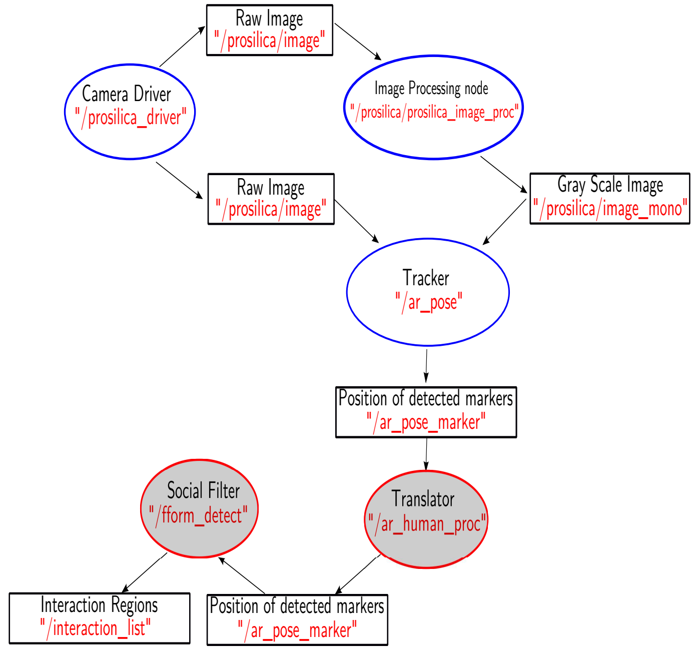

Fig. 5. Diagram showing the communication between the different nodes running in the remote computer (connected to the camera) The rectangles are topics where information is exchanged between two or more nodes (ellipses). Grey elipsis are the nodes being developed by our team.

emergency bumpers sensors (contact switches) and 2 Kinect sensors.

The mobile base has a rectangular footprint with dimensions 0.56 m long by 0.67 m wide, however, the dimensions including the attached seat and protections is of 1.48 m height, 1.08 m long by 0.67 m wide. The autonomous wheelchair can carry a maximum payload of 150 kg with a maximum nominal linear velocity of 1.39 m/s and a maximum rated angular velocity of 1.5 rad/s. Its maximum acceleration is rated at 1.35 m/s^2.

V. Software Architecture

The system architecture has been developed using the Robot Operating System (ROS) [15]. ROS is used to get some functionalities like hardware abstraction, low-level device control, message-passing between processes and package management.

The fundamental concepts of the ROS implementation are nodes, messages, topics, and services. Nodes communicate with each other by passing messages. A message is an strictly typed data structure. Messages can be composed of other messages, and arrays of other messages, nested arbitrarily deep. A node sends a message by publishing it to a given topic. The nodes that are interested in a certain kind of data will subscribe to the appropriate topic. There may be multiple concurrent publishers and subscribers for a single topic, and a single node may publish and/or subscribe to multiple topics. In general, publishers and subscribers are not aware of each others existence.

The Diagram of the processes running in the remote and on-board computers are displayed in figure 5 and 6 where each process/node is shown as an ellipsis while the topics are rectangles. Nodes that are developed by our team are presented in grey.

All our implementation uses a publisher/subscriber communication paradigm where each nodes works at its own frequency. Due to that, it is necessary to validate input data timing in some nodes in order to avoid receiving too old information. This validation is done by posting a time stamp on each message so that the subscriber can always know when the received data was published and decide whether it is good or not.

ROS currently supports TCP/IP-based and UDP-based message transport. The TCP/IP-based transport is known as TCPROS and streams message data over persistent TCP/IP connections. TCPROS is the default transport used in ROS and is the only one used in this work.

In figure 6, it can be observed the transformation system, which is the service in charge of the tracking of spatial relationships as for example those between the mobile robot

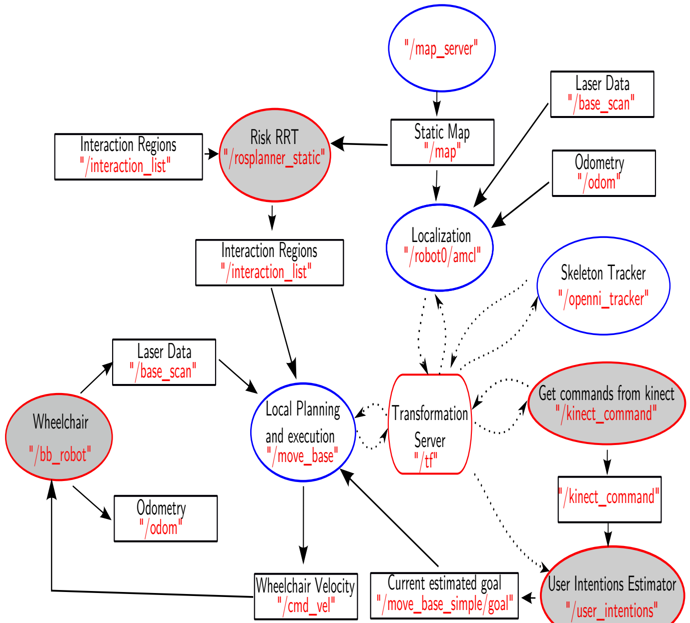

Fig. 6. Diagram showing the communication between the different nodes running in the on-board computer. The ROS *tf* system is in charge to compute the transformations between different reference frames

and the world fixed frame of reference for localization, (e.g. those provided by the kinect *openni_tracker*, *amcl* localization, etc).

This system is called *tf*. The *tf* system constructs a dynamic transformation tree which relates all frames of reference in the system. As information streams in from the various subsystems of the robot (joint encoders, localization algorithms, etc.), the *tf* system can produce streams of transformations between nodes on the tree by constructing a path between the desired nodes and performing the necessary calculations.

The relationship between coordinate frames are maintained in a tree structure buffered in time, so that it is possible to transform points, vectors, etc between any two coordinate frames at any desired point in time.

Nodes that need to add some reference frame to the tree use a broadcaster which is represented as the doted lines going from any node to the transformation server in figure 6. Listeners are services that get the values of a given transformation between two reference frames (doted arrows from *tf* server to any of the other nodes).

VI. Experimental Results

The system was evaluated at INRIA's hall shown in figure 3. Two possible scenarios were considered. In the first one the wheelchair moves in an static environment with no humans just to test the performance of the user intentions estimation algorithm. The second one considers the presence of humans moving and interacting around the wheelchair.

At the beginning the user is asked to do the calibration of the Kinect used as input device. This allows the Kinect

Fig. 7. A user pointing to his desired destination. The idea is to be able to understand which are the most probable goal given the direction of the gesture

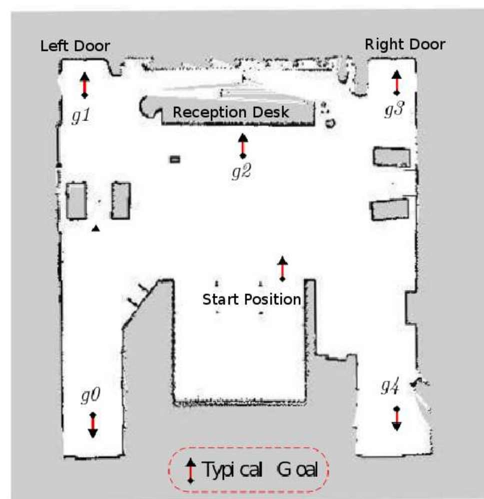

Fig. 8. Typical user destinations in this scenario are marked with an small arrow

tracker to retrieve the information relating the links of the user skeleton (head, neck, torso, shoulders, elbows and hands).

The wheelchair is located in an initial position, and the user starts the movement by pointing towards his intended destination as shown in figure 7. The commanded direction is read as the angle formed by the torso and the right hand of the user. A set of typical destinations were dened into the map as shown by the small arrows in figure 8. When the command is read the user estimation module computes the goal with the highest posterior probability and send it to the navigation module.

The navigation module receives the map of the environment, the currently computed goal, the list of people present in the scene and plan its trajectory. While moving it maintains a path with the highest probability of success to reach the goal and computes the velocity commands (linear velocity, angular velocity) that is sent to the wheelchair. Figure 9 shows the path followed by the wheelchair when there are no dynamic obstacles or humans in the scene. The rectangle is the footprint of the wheelchair.

In the second scenario two persons are talking and they are

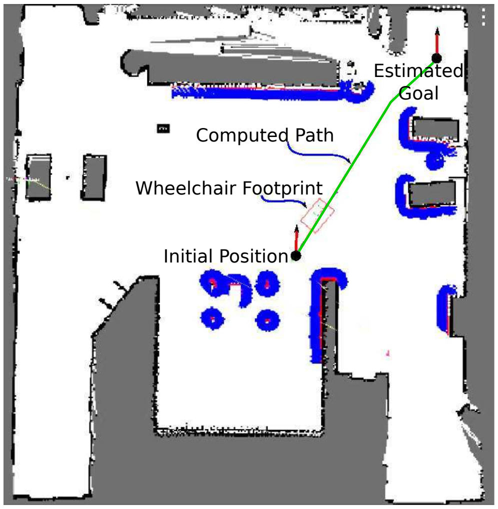

Fig. 9. Results obtained with the wheelchair moving without any obstacle in the path

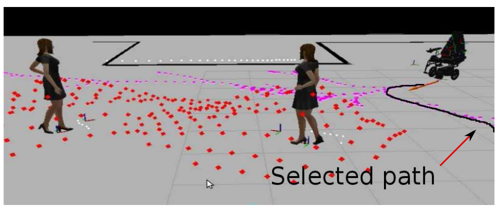

Fig. 10. Socially accepted navigation. Even if the intention of the user is to go to the goal just in front of him, the navigation algorithm is able to plan a path that reaches the goal while avoiding interrupting a conversation between the other two persons. The points around the persons shows the computed personal space.

positioned in the middle of the path between the wheelchair and the current estimated goal. The user points to the goal that is located just in front of him to select the desired position and he/she dont have to worry about the necessary planning and commands to avoid interrupting the conversation because it is the autonomous navigation system the one that takes this responsibility. As it can be seen in figure 10 the space between the two persons is big enough to let the robot to pass by if the social interaction cost is not considered. Standard navigation algorithms would have disturbed the conversation, producing an uncomfortable situation for both the user and the people around him.

VII. Conclusion and Future Work

The proposed experimental platform is an ongoing effort and the results we have obtained should be considered preliminary. The most important results up to this point are:

- *Tracking*: We are still developing and testing different tracking methods. Meanwhile, we have performed several tests using augmented reality markers (wore as hats). This has allowed us to validate the overall architecture, even if it is not a viable solution in the long run.
- *Prediction*: The proposed prediction algorithms have been extensively validated and compared about other state of the art techniques [13]. Our approach consistently yields comparable predictions with much smaller models and is able to update its knowledge as new motion patterns are observed.
- *Planning*: The RiskRRT algorithm has been extensively tested in simulation. It is now implemented in our real platform, where it will be tested against similar approaches to assess the actual impact that integrating risk estimation and trajectory prediction has in terms of safety.
- *Socially acceptable behavior is very important*. Even in our scripted tests, both interacting people and the wheelchair's user reported that they felt very uncomfortable when the robot passed right through the middle of a talking group.
- *Predictive behavior and socially acceptable behavior are often similar*. The use of the social lter and prediction module as part of the navigation algorithm increases the user comfort by avoiding embarrassing situations as disturbing people around him and even more it avoids dangerous situations as crashing due to its capability to avoid even dynamic obstacles. For example, when pedestrians were passing through the robot's path, it often happened that it stopped (knowing that the path was going to be free) to let the person pass. This seems to indicate that in many cases, knowing how people will move, the most reasonable thing to do is to be polite. It also suggests game theory as a possible way to analyze these interactions.
- *User intentions estimation*. The user intention algorithm has proven to be useful to translate the input commands taken from typical input devices into high level orders (goals). Even in the cases when the system cant decide accurately which is the intended goal, as this is a probabilistic approach we still can get useful information from the system in order to assess the amount of uncertainty in the estimation. This information can be used to evaluate the need to ask to the user for some extra information in order to solve the ambiguity. In order to work in a non-supervised environment a sophisticated/accurate user intention algorithm combining machine learning techniques is desired in order to add the capability to adapt autonomously to the user disability.
- *Kinect as input device*. Using the Kinect as input device can be good for the elderly because it provides a more natural way of interaction when giving directions (pointing to the desired direction is more natural than trying to control the wheelchair using a joystick) so they can be more confident when using the wheelchair. Validation of the method with other user-machine interfaces would be useful to take into account people who does not have the necessary strength or motor skills to move their arms.

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